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LETTER TO EDITOR

Laser-induced Micro-explosion: A Micro-zone Explosive Simulator for the Characterization of Explosives

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ABSTRACT

The determination of detonation performance and sensitivity is an important research content of explosive testing technology. However, the traditional test method usually requires a large amount of samples due to the limitation of the critical diameter and other detonation conditions. Therefore, it will inevitably bring great test risk, high test cost and measurement uncertainty. In this case, it is urgent to develop new testing technology with small dosage and high precision. Recently, a micro-zone explosive simulator for the characterization of explosives is proposed by Wang and Liu et.al. According to their work, laser-induced micro-explosion is produced by micrograms of explosives irritated by pulsed laser, has been proved to be closely related to macroscopic detonation. Therefore, it can be used as a micro-zone explosive simulator for the characterization of explosives. The aim of this letter is to shed new light on the determination of detonation performance and sensitivity and highlighted the importance of close integration of experimental, statistical, and theoretical efforts.

KEYWORDS

Laser-induced plasma, detonation performance, sensitivity, micro-zone explosive simulator.

Energetic materials (EMs), especially explosives, are important carriers to maintain national security. These materials also have substantially contributed to the progress and prosperity of humankind. The determination of detonation performance and sensitivity is of great significance for the reasonable application, formula design, storage, and transportation of explosives [**1**]. Detonation performance, such as detonation velocity, detonation pressure, and so on, are pivotal parameters in the assessment of destructive power. Traditional performance testing methods require real detonation with a large dose of explosives, grams to kilograms for one test. Thus, it will bring high risks and costs [**2,3**]. Sensitivities are some crucial characteristics for evaluating the safety of EMs, including impact sensitivity, friction sensitivity, and electrostatic sensitivity depending on different external stimuli. The most frequently used measurements for sensitivity need multiple tests based on the blast probability method [**4**]. In this case, some newly synthesized explosives are insufficient to complete a single test. And the test error is up to 20% or more [**5**]. Here comes the question, can we develop an advanced explosion testing technology that only needs a small dose of samples, no detonation risks, high-speed and high accuracy?

Recently, the transitory bombardment of the high-energy laser pulse (typically a few nanoseconds) and EMs has been considered as an emerging technique for the characterization of the high-temperature chemistry and performance of EMs [**6**]. Gottfried *et. al.* [**7,8**] utilized the velocity of laser-induced air shockwave to estimate detonation velocity and energy release rates of explosives and reactive materials. The detonation velocity measurement error is within 5%, but nothing can be done for the sensitivity parameters and other detonation indexes.

Matthew *et. al.* [**9**] collected the shadowgraphy images by using interframe times ranging from 50–750 ns, but no difference was observed between the EMs for the majority of the time domain characterized (0–12 μs). Wang and Liu *et. al.* proposed a novel rapid detection technique for explosive performance and sensitivity with a small dose, no detonation risks, and high accuracy in the light of a comprehensive analysis of the interaction between pulsed laser and several micrograms of EMs. By consuming micrograms of a sample, multiple explosion parameters can be acquired simultaneously. And the average relative error for sensitivities is within 10%, and for detonation parameters is within 5%. And the events on nanosecond to millisecond time scales, including laser-induced plasma spectra, laser-induced air shock waves, and laser-induced deflagration in chronological order are defined as laser-induced micro-explosion. Based on a self-assembled micro-explosion test system [**10**] and a detailed investigation of the physical theory and statistical analysis of laser-induced micro-explosion reaction, they built up a reliable association with laser-induced micro-explosion and macroscopic detonation, thus the laser-induced micro-explosion can be regarded as a micro-zone explosive simulator to reveal some key detonation information at the micro level [**10**]. The prediction of enthalpy of formation and detonation via micro-zone explosive simulator pressure is never reported before. Moreover, laser-induced plasma spectra are widely used for online quantitative analysis of elements [**11,12**], but they firstly found there is a certain correlation between the sensitivity and the laser-induced plasma spectra, such as impact and plasma temperature, friction sensitivity, and electron density, electrostatic sensitivity, and oxygen balance, as well as laser sensitivity and thermal conductivity. Combined with the characteristic spectra, the statistical algorithm, and the physical parameter modification, the sensitivity prediction models of impact, friction, electrostatic, and laser can be well established, and the average relative error of the prediction models is less than 10% [**13**]. This work pioneered a new sensitivity prediction method with low cost and high accuracy.

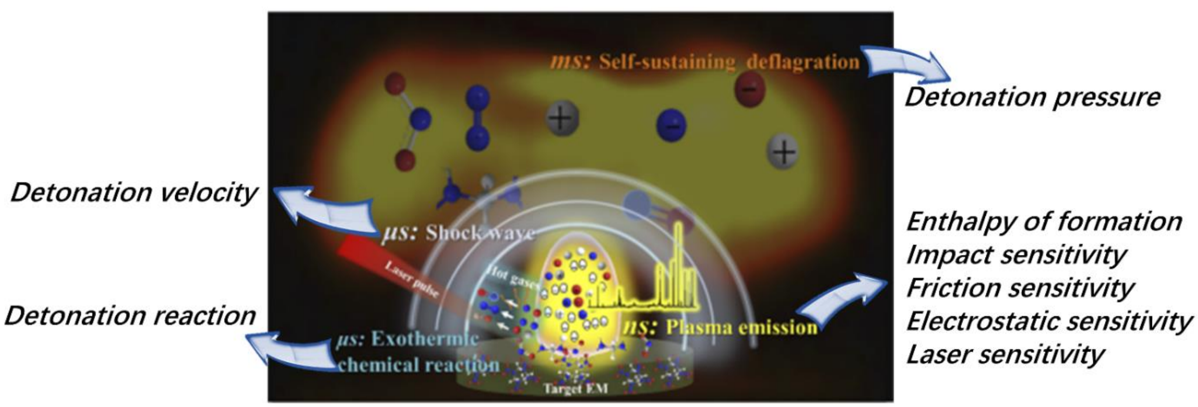

Fig. 1. The micro-zone explosive simulator.

To sum up, Wang and Liu's work provides a new method for small dosage explosives tests. The micro-zone explosive simulator is characterized by multi-parameter simultaneous detections as shown in **Fig. 1**. It is expected to be an alternative to traditional testing methods. In the future, the explosive testing technology will gradually move from macro to micro, from phenomenology to essence. The rapid diagnosis of the small explosive charges based on the micro-zone explosive simulator will be a "dream tool" in the field of "high precision" performance assessment of EMs.

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CONFLICTS OF INTEREST

There are no conflicts to declare.

REFERENCES

1. Mathieu, D.; *Industrial & Engineering Chemistry Research*, **2017**, *5*, 29, 8191. <https://doi.org/10.1021/acs.iecr.7b02021>
2. Trzciński, W.A.; Cudziło, S.; Szymańczyk, L.; *Engineering Transactions*, **2001**, *49*, *4*, 443. <https://doi.org/10.24423/engtrans.537.2001>
3. Hargather, M.J.; Settles, G.S.; *Shock Waves*, **2007**, *17*, *4*, 215. < https://doi.org/10.1007/s00193-007-0108-8 >.
4. Zeman, S.; Jungová, M.; *Propellants, Explosives, Pyrotechnics*, **2016**, *41*, *3*, 426. <https://doi.org/10.1002/prep.201500351>
5. Li, G.; Zhang, C.; *Journal of Hazardous Materials*, **2020**, *398*, 122910. <https://doi.org/10.1016/j.jhazmat.2020.122910>
6. Gottfried, J.L.; *AIP Conference Proceedings*, Vol. 1979. No. 1. AIP Publishing LLC, 2018. <https://doi.org/10.1063/1.5044886>
7. Gottfried, J.L.; Klapötke, T.M.; Witkowski, T.G.; *Propellants, Explosives, Pyrotechnics*, **2017**, *42*, *4*, 353. <https://doi.org/10.1002/prep.201600257>
8. Wainwright, E.R.; De Lucia, F.; Weihs, T.P.; Gottfried, J.L.; *Spectrochimica Acta Part B: Atomic Spectroscopy*, **2021**, *183*, 106270. <https://doi.org/10.1016/j.sab.2021.106270>
9. Biss, M.M.; Brown, K.E.; Tilger, C.F.; *Propellants, Explosives, Pyrotechnics*, **2020**, *45*, *3*, 396. <https://doi.org/10.1002/prep.201900130>

10. Wang, X.; Liu, R.; He, Y.; et al; *Optics Express*, **2022**, *30, 4*, 4718. <https://doi.org/10.1364/OE.449382>
11. Wang, X.; Wan, S.; He, Y.; et al; *Spectrochimica Acta Part B: Atomic Spectroscopy*, **2021**, *178*, 106123. <https://doi.org/10.1016/j.sab.2021.106123>
12. Wang, X.; Li, A.; Xu, X.; et al; *Spectrochimica Acta Part B: Atomic Spectroscopy*, **2020**, *174*, 105996. <https://doi.org/10.1016/j.sab.2020.105996>
13. Wang, X.; Wang, J.; Fu, Y.; et al; *Journal of Analytical Atomic Spectrometry*, **2021**, *36, 12*, 2603. <https://doi.org/10.1039/D1JA00325A>

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